TECHNICAL DETAILS
ARPA RADIO PROPAGATION TEST SET

COLLINS

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1.0 INTRODUCTION

The following information relative to the characteristics of the ARPA propagation test set has been prepared specifically for the November 8-9 ARPA Packet Radio Team. It is planned that the test set characteristics will be documented in more detail in a Packet Radio Note. The details of the design of this test set have been worked between ARPA, SRI and Collins Radio and until now other members have not been given much visibility of the equipments to be used in the planned test program. It is hoped that the following information, as well as the lab demonstrations, will help to correct this deficiency.

2.0 PURPOSE

The propagation test set has been designed to support the packet radio propagation measurement program outlined in Packet Radio Note #56. Emphasis in this test program is to be given to propagation characteristics that are most significant to transmission of digital signals. A large amount of reliable measured data exists which provides sufficient information to predict path attenuation in the various environments in which the packet radio system is to operate, but there exists very little information relative to the multipath spread characteristics and the short period distribution of impulsive noise. These characteristics will have a very significant impact on both system and equipment design for the packet radio systems. The propagation test set has been

designed primarily to provide more information on these two important characteristics, but also will provide facilities to measure net path loss and doppler spread. Since both the obstruction attenuation and noise level is expected to vary with frequency, measurements are to be made at two frequencies (430 and 1325 MHz). These frequencies represent the approximate frequency limits which are now considered practical for packet radio systems (limited on the low end by frequency channel availability and on the high end by excessive path loss and transmit power output).

3.0 EQUIPMENT CHARACTERISTICS

Block diagrams of the transmitter and receiver are shown in Figures 3-1 and 3-2 respectively. Summary specifications for these units follow.

3.1 Transmitter Characteristics

A. Frequency Band - The transmitter may be operated simultaneously on two fixed frequencies of 430 and 1325 MHz. These frequencies are precisely controlled through a synthesizer referenced to a precision 10 MHz oscillator. Output spectrum under spread modulation conditions is limited by the transmit bandpass filter. Frequency changes can be made in a relatively simple manner changing the synthesizer and by changing the output filter.

B. Frequency Stability - The frequency stability of the radiated signal is controlled by the reference oscillator, whose aging characteristic is 5×10^{-10} per day and 1×10^{-11} per 100 seconds. This stability is required only for doppler measurements.

C. Power Output - Nominal 10 watts at 430 MHz and 5 watts at 1325 MHz.

designed primarily to provide more information on these two important characteristics, but also will provide facilities to measure net path loss and mobile speed. Although both the observation attenuation and noise level is reported to calibrated frequency, measurements are to be made at two frequencies, 420 and 1325 MHz. These frequencies represent the approximate frequency limits which are now considered practical for packet radio systems (limited on the low end by frequency channel availability and on the high end by excessive path loss and transmit power output).

3.0 EQUIPMENT CHARACTERISTICS

Block diagrams of the transmitter and receiver are shown in Figures 3-1 and 3-2 respectively. Summary specifications for these units follow.

3.1 Transmitter Characteristics

a. Frequency Band - The transmitter may be operated simultaneously on two fixed frequencies of 420 and 1325 MHz. These frequencies are precisely controlled through a synthesizer referenced to a precision 10 MHz oscillator. Output spectrum under spread modulation conditions is limited by the transmit bandpass filter. Frequency changes can be made in a relatively simple manner changing the synthesizer and by changing the output filter.

b. Frequency Stability - The frequency stability of the radiated signal is controlled by the reference oscillator, whose aging characteristic is 5×10^{-10} per day and 1×10^{-11} per 100 seconds. This stability is required only for Doppler measurements.

c. Power Output - Nominal 10 watts at 420 MHz and 5 watts at 1325 MHz.

D. Modulation - The system may be operated in a CW mode for doppler and path loss measurements and in a bi-phase modulated spread spectrum mode for multipath measurements. For the spread modes, chip rates of 10 and 20 MHz are provided. The code word is a maximum length 127 chip PRN code. Twelve transmit modes are provided which are various combinations of carrier, bi-phased modulated code and blank periods. These modes are selectable from the front panel of the transmit control unit or by a 4-bit binary word from a remote control. The remote control interface is at TTL logic level. The 12 modes are tabulated below.

ABCD	CONTROL OPTIONS
CONTROL INPUT	RESPONSE
0000	STANDBY, CARRIER OFF
0001	140MHZ CW (DOPPLER)
0010	CONTINUOUS PRN, 10MHZ
0011	CONTINUOUS PRN, 20MHZ
0100	CODE/1 BLANK, 10MHZ
0101	CODE/1 BLANK, 20MHZ
0110	CODE/3 BLANK, 10MHZ
0111	CODE/3 BLANK, 20MHZ
1000	CODE/1 CARRIER, 10MHZ
1001	CODE/1 CARRIER, 20MHZ
1010	CODE/3 CARRIER, 10MHZ
1011	CODE/3 CARRIER, 20MHZ

3.2 Receiver

The receiver is designed to receive either of the two transmitted frequencies. Simultaneous operation is not possible since all circuitry following the IF preamplifiers is common to the two channels. Channel selection is by means of IF frequency switching. The receiver employs low noise transistor preamplifiers prior to the down converter in each channel and hence, the noise figure on either channel is less than 5 db. The choice of 140 MHz for the IF frequency was dictated by the surface acoustic wave correlators. The receiver provides sufficient gain to amplify the front end noise to operate the AGC. Therefore, when in the AGC mode, the IF output signal is maintained constant for any input signal level down to almost 0 db signal noise in the approximate 50 MHz bandwidth of the receiver. The surface wave correlator provides approximately 20 db of processing gain and it is anticipated that the system will be operated at receive signal levels that approach unity signal to noise in the IF bandwidth. Summary specifications follow.

A. Frequency Bands

430 and 1325 MHz switch selectable. The front panel connector is provided for external local oscillator injection which allows the receive center frequency to be tunable over the approximate 50 MHz bandwidth of the input filters. It is anticipated that this feature might be used in conjunction with the narrow band filter to aid in identification of narrow band interferors.

B. Bandwidth

Wideband mode approximately 50 MHz, narrowband mode approximately 500 KHz, doppler mode approximately 100 Hz (limited by the low pass filter at the output of the doppler phase detectors.)

C. Frequency Control

All frequencies are locked to a precision crystal oscillator whose aging drift is 5 X 10^{-10} per day.

D. IF Frequency

Nominal 140 MHz. Note: This frequency has been offset downward 20 KHz to 139.980 because of the manufacturing tolerances in producing the SAWD.

E. Gain Control Range

AGC 60 db minimum; manual control 60 minimum.

F. Correlators

127 chip code, 10 MHz chip rate,
127 chip code, 20 MHz chip rate.
Correlated signal detection - envelope detector with peak output level of 5 volts.

G. Displays

2 meters showing the output of doppler I and Q channels,
1 meter showing relative signal strength.
Indicator lights for each of the 6 thresholds of the noise threshold detector.

H. Noise Measurement

The system used for measurement of noise consists of 6 threshold detectors which will be normally set at signal level steps of 10 db. Detector output at the logic 1 (ECL level) when the noise exceeds the preset threshold. The hysteresis between the on and off condition of the threshold detector is less than 1 db. The response time of the threshold detector is less than 10 nanoseconds. The input to the threshold detector may be band limited by the wideband channel, narrowband channel, or the SAWDS. Additional gain is provided in the narrowband channel

which may be adjusted to a value equal to the bandwidth ratio between the wide and narrow bandwidths so that the detector threshold level may be set to operate at a constant spectral density regardless of the bandwidth chosen. The threshold detector is to be mounted external to the receiver drawer with the equipment used to record the statistical distribution of noise. The interface to the receiver is by means of a 140 MHz IF cable and by power control cables. An LED indicator is provided on the receiver front panel and on the module for each threshold level to facilitate adjustment of the threshold. It is intended that these be valuable only for the CW calibration of the system since in normal operation the indicator will not be on for a sufficient time to provide an indication of impulsive noise.

4.0 CORRELATOR CHARACTERISTICS

The 127 chip code for the surface wave correlator was chosen for minimum sidelobes in a cyclic mode (i.e., code continuously repeated). The technique used for code selection is documented in ARPA Packet Radio Note #73. A computer program was also developed to aid in determining the effect of filters and interference on the correlator output. This program and samples of the output are documented in Note #76.

Scope pictures of the SAWD output in the cyclic and non-cyclic mode are shown in Figures 4-1 and 4-2. These pictures represent the performance with no band limiting other than that inherent in the SAWD. However, considerable band limiting exists in the SAWD input and output matching networks; hence, it is expected that the transmit output filter and the receiver preselector and IF band limiting filters will not cause significant added degradation in the peak to sidelobe characteristics.

In the non-cyclic mode the transmission of one code burst is followed by one or 3 code periods of no signal. This mode is provided only for resolution of multipath delays that exceed one code period (6.35 or 12.7 microseconds). Since these delays correspond to increased path lengths of about 1.2 and 2.4 miles, it is not anticipated that multipath of significant level will exist that will require the use of the non-cyclic mode.

5.0 OPERATING RANGE

The ability of the system to resolve echoes is limited by signal to noise and by the correlator sidelobe characteristics. The expected range performance is plotted in Figure 5-1. The ordinate scale is shown as signal margin in db above 0 db S/N in 50 MHz bandwidth of the IF amplifier. This should be viewed as the margin available relative to a line of sight path, for purpose of measuring obstruction loss. Due to the processing gain of the SAWD, 0 db S/N in the receiver 50 MHz bandwidth results in a S/N at the correlator output of about 20 db. This is expected to be about the minimum S/N useful to resolve multipath. For this reason, it was not considered necessary for the AGC reference to be derived from the correlator output. The AGC control is derived from total signal plus noise and AGC control does not extend below 0 db S/N, ref to IF 50 MHz bandwidth, or about 20 db S/N referenced to the SAWD output.

The equipment and system parameters used in defining the curves plotted in Figure 5-1 are tabulated below.

Transmitter Output:

At 430 MHz,	10 watts (+40 DBM)
At 1325 MHz,	5 watts (+37 DBM)

<u>Antenna Gains:</u>

Transmit Antenna:	
430 MHz,	G = 2 DBI
1325 MHz,	G = 2 DBI Dipole Ant
1325 MHz,	G = 7.5 DBI, 6 Element Array
Receive Antenna:	
Gain =	2 DBI at 430 and 1325 MHz
Receiver Noise Figure:	
NF =	5 DB (max) at 430 and 1325 MHz
Receiver Bandwidth =	50 MHz

6.0 ANTENNAS

Two types of antennas are being supplied with the test set. Two low gain dual frequency antennas have been fabricated. A picture of the low gain antenna is shown in pictures attached. The antenna consists of a vertical halfwave dipole at each frequency. These are stacked colinearly and are isolated by choke sections. The 1325 MHz antenna is placed on bottom to minimize elevation plane sidelobes when the antenna is mounted above a ground plane such as the test van roof. The antenna is enclosed in a fiberglass housing for protection.

One model of a second design is also being fabricated. This antenna provides increased gain at 1325 MHz only. The 430 MHz portion of the antenna is identical to that used on the low gain design. The high frequency section consists of a 6 element colinear array providing about 7.5 dbi gain at 1325 MHz. The elevation plane test patterns of the engineering model are shown in Figure 6-4. The half power beam width in the elevation plane is less than 10°. Pattern in the azimuth plane is essentially circular. It is intended that this antenna be used at the transmit location only. It is anticipated that a similar antenna would be used at a packet radio repeater to minimize the transmit power required at both the terminal and repeater and to reduce interference from strong interferors that are close to the antenna but are below the horizon angle and, hence, are below the peak of the beam.

NOTES:
1. A2A4
430MHZ CTR FREQ
40MHZ BW
2 POLE FILTER
TBA 430-40-2SS

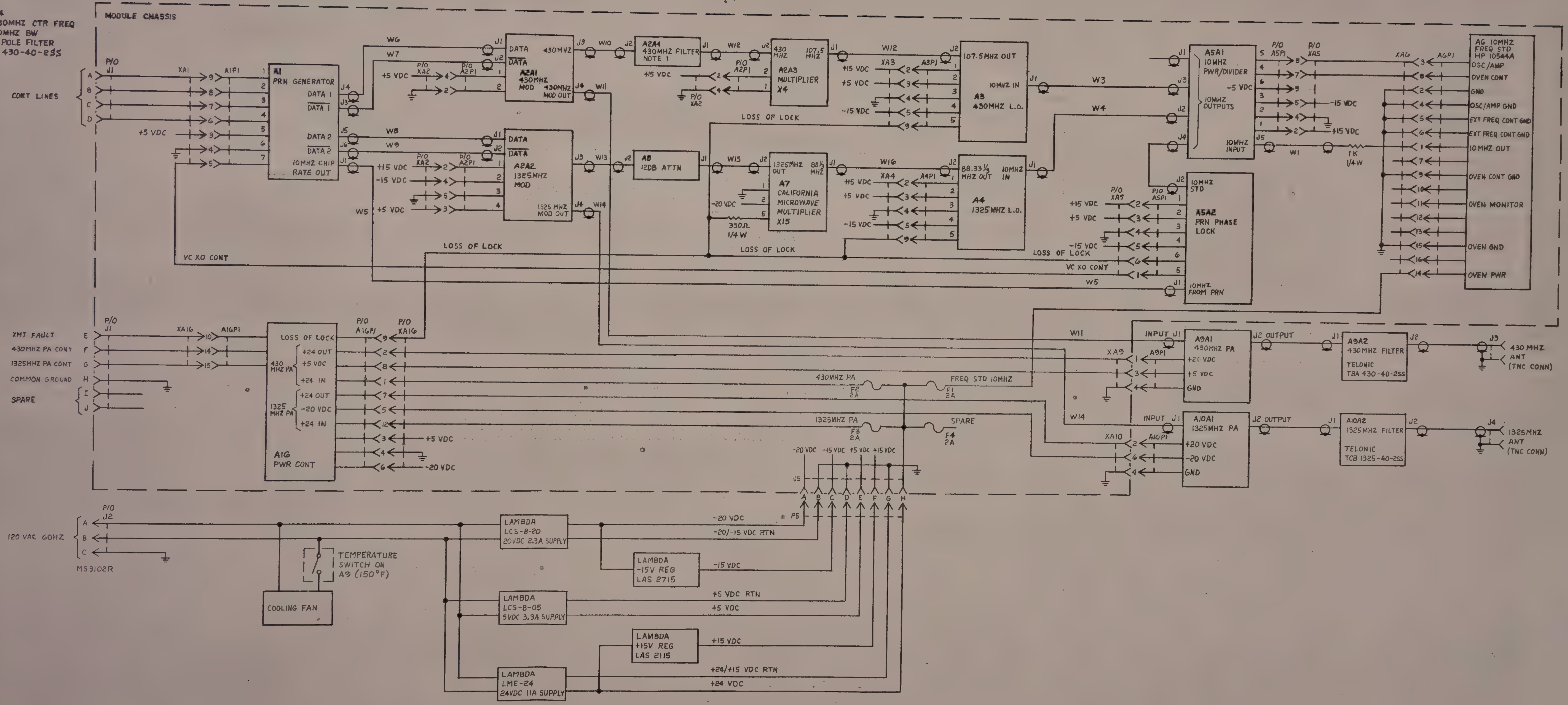
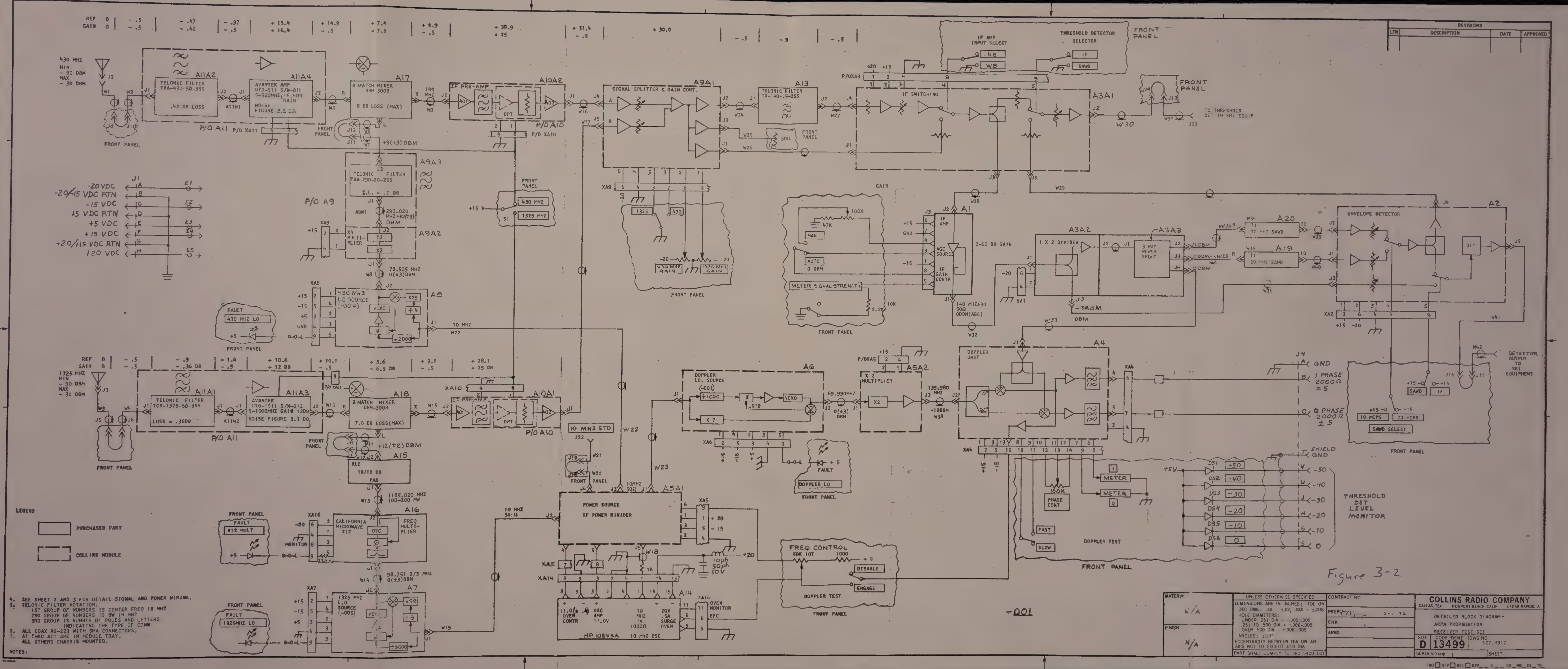


Figure 3-1

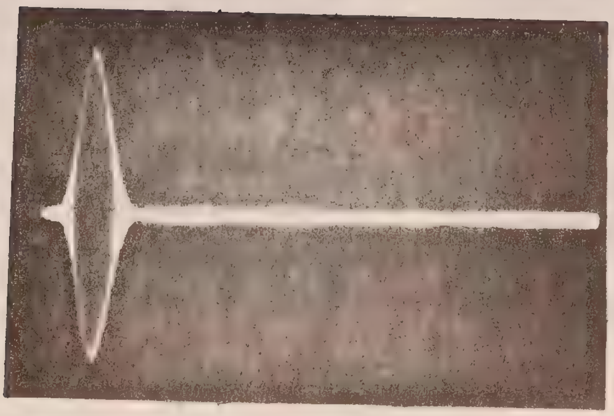
REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

CONTRACT NO.	COLLINS RADIO COMPANY — DALLAS, TEX · NEWPORT BEACH, CALIF · CEDAR RAPIDS, IA
PREP R.W. Kluglat 11-6-73	BLOCK DIAGRAM XMTR TEST SET ARPA PROPAGATION
CHK	
APVD	SIZE DH · CODE IDENT 13499 · DWG NO.
	SCALE NONE · SHEET



430 MHZ
MIN - 90 DBM
MAX - 30 DBM
A11A2
TELONIC FILTER
TBA-430-50-3SS
.42 DB LOSS
A11A4
AVANTEK AMP
UTO-511 S/N-011
5-500MHZ, 16.4DB GAIN
NOISE FIGURE 2.2 DB
A17
DBL BAL MIXER
DBM 3008
8 DB LOSS (MAX)
140 MHZ
IF PRE-AMP
A10A2
P/O A10
P/O A11
SIGNAL SPLITTER & GAIN CONT.
A9A1
A13
TELONIC FILTER
TX-140-.5-2SS
IF SWITCHING
A3A1
FRONT PANEL
TO THRESHOLD DET IN SRI EQUIP
IF AMP INPUT SELECT
NB
WB
THRESHOLD DETECTOR SELECTOR
IF
SAWD
A9A3
TELONIC FILTER
TBA-290-20-2SS
I.L. - .7 DB
290.020 MHZ +10(±3) DBM
A9A2
X4 MULTIPLIER
72.505 MHZ 0(±3)DBM
A8
430 MHZ LO SOURCE (-004)
VCXO
10 MHZ
FAULT
430 MHZ LO
430 MHZ
1325 MHZ
-20VDC
-20/15 VDC RTN
-15 VDC
+5 VDC RTN
+5 VDC
+15 VDC
+20/+15 VDC RTN
+20 VDC
GAIN
A1
IF AMP
AGC SOURCE
IF GAIN CONTR
MAN
AUTO
0 DBM
METER SIGNAL STRENGTH
0-60 DB GAIN
140 MHZ±30 50Ω DBM(AGC)
A3A2
1 X 2 DIVIDER
A3A3
3-WAY POWER SPLAT
A20
T1 10 MHZ SAWD
A19
T1 20 MHZ SAWD
A2
ENVELOPE DETECTOR
DET
1325 MHZ
MIN - 90 DBM
MAX - 30 DBM
A11A1
TELONIC FILTER
TCB-1325-50-3SS
LOSS - .36DB
A11A3
AVANTEK
UTO-1511 S/N-012
5-1500MHZ GAIN 12DB
NOISE FIGURE 3.3 DB
A18
DBL BAL MIXER
DBM-3008
7.0 DB LOSS(MAX)
A10A1
10 MHZ STD
A15
RLC
10/12 DB PAD
1185.020 MHZ 100-200 MW
A16
CALIFORNIA MICROWAVE X12
OSC
FREQ MULTIPLIER
FAULT
X12 MULT
MONITOR
98.751 2/3 MHZ 0(±3)DBM
A7
1325 MHZ L.O SOURCE (-005)
VCXO
X99
FAULT
1325MHZ LO
A6
DOPPLER LO. SOURCE (-003)
VCXO
X 7
69.990MHZ 0(±3) DBM
A5A2
X 2 MULTIPLIER
139.980 MHZ +10DBM
FAULT
DOPPLER LO
A5A1
POWER SOURCE
RF POWER DIVIDER
10MHZ 50Ω
A14
11.0(+.4) OVEN CONTR
OSC AMP 11.0V
10 MHZ 1V 1000Ω
20V .5A SURGE OVEN
OVEN MONITOR
EFC
HP 10544A 10 MHZ OSC
FREQ CONTROL
50K 10T
1000
DISABLE
ENGAGE
DOPPLER TEST
A4
DOPPLER UNIT
PHASE CONT
METER
FAST
SLOW
DOPPLER TEST
J4
GND
I PHASE 2000Ω ±5
Q PHASE 2000Ω ±5
SHIELD GND
-50
-40
-30
-20
-10
0
THRESHOLD DET LEVEL MONITOR
DETECTOR OUTPUT TO SRI EQUIPMENT
SAWD
IF
10 MCPS
20 MCPS
SAWD SELECT
LEGEND
PURCHASED PART
COLLINS MODULE
4. SEE SHEET 2 AND 3 FOR DETAIL SIGNAL AND POWER WIRING.
3. TELONIC FILTER NOTATION:
1ST GROUP OF NUMBERS IS CENTER FREQ IN MHZ
2ND GROUP OF NUMBERS IS BW IN MHZ
3RD GROUP IS NUMBER OF POLES AND LETTERS INDICATING THE TYPE OF CONN
2. ALL COAX RG-223 WITH SMA CONNECTORS.
1. A1 THRU A11 ARE IN MODULE TRAY. ALL OTHERS CHASSIS MOUNTED.
NOTES:
-001
MATERIAL N/A
FINISH N/A
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES; TOL ON DEC DIM: .XX ±.02, .XXX ±.008
COLLINS RADIO COMPANY
DALLAS, TEX NEWPORT BEACH, CALIF CEDAR RAPIDS, IA
DETAILED BLOCK DIAGRAM - ARPA PROPAGATION RECEIVER TEST SET
SIZE D
CODE IDENT 13499
DWG NO 627-8317
REVISIONS

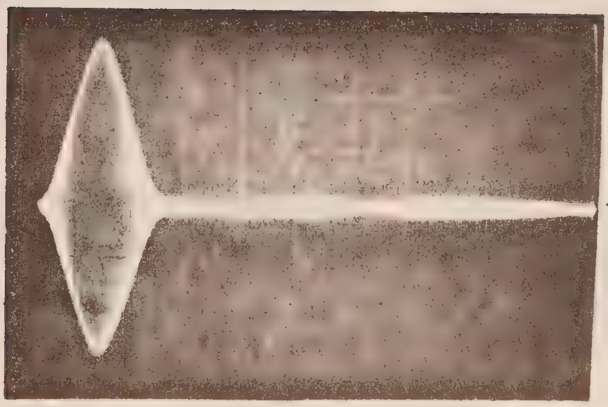
Figure 3-2



27 db

100 ns

20 mcps SAWD



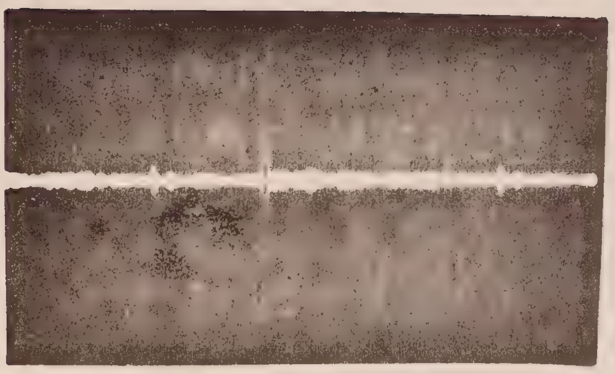
25 db

100 ns

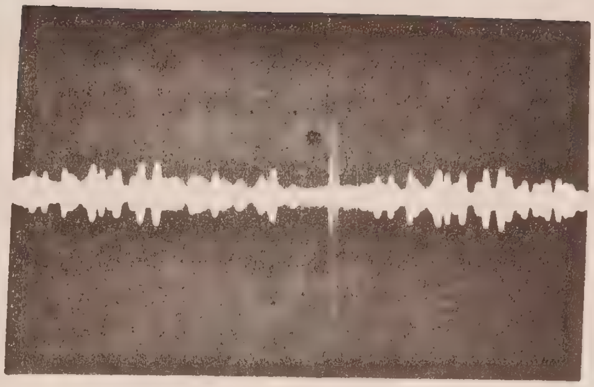
10 mcps SAWD

Figure 4-1

CYCLIC WAVEFORMS OF 10 mcps AND 20 mcps SAWD



Cyclic



Non-Cyclic

20 mcps SAWD

Cyclic

Non-Cyclic

10 mcps SAWD

Figure 4-2

CYCLIC & NON-CYCLIC SIDELOBES

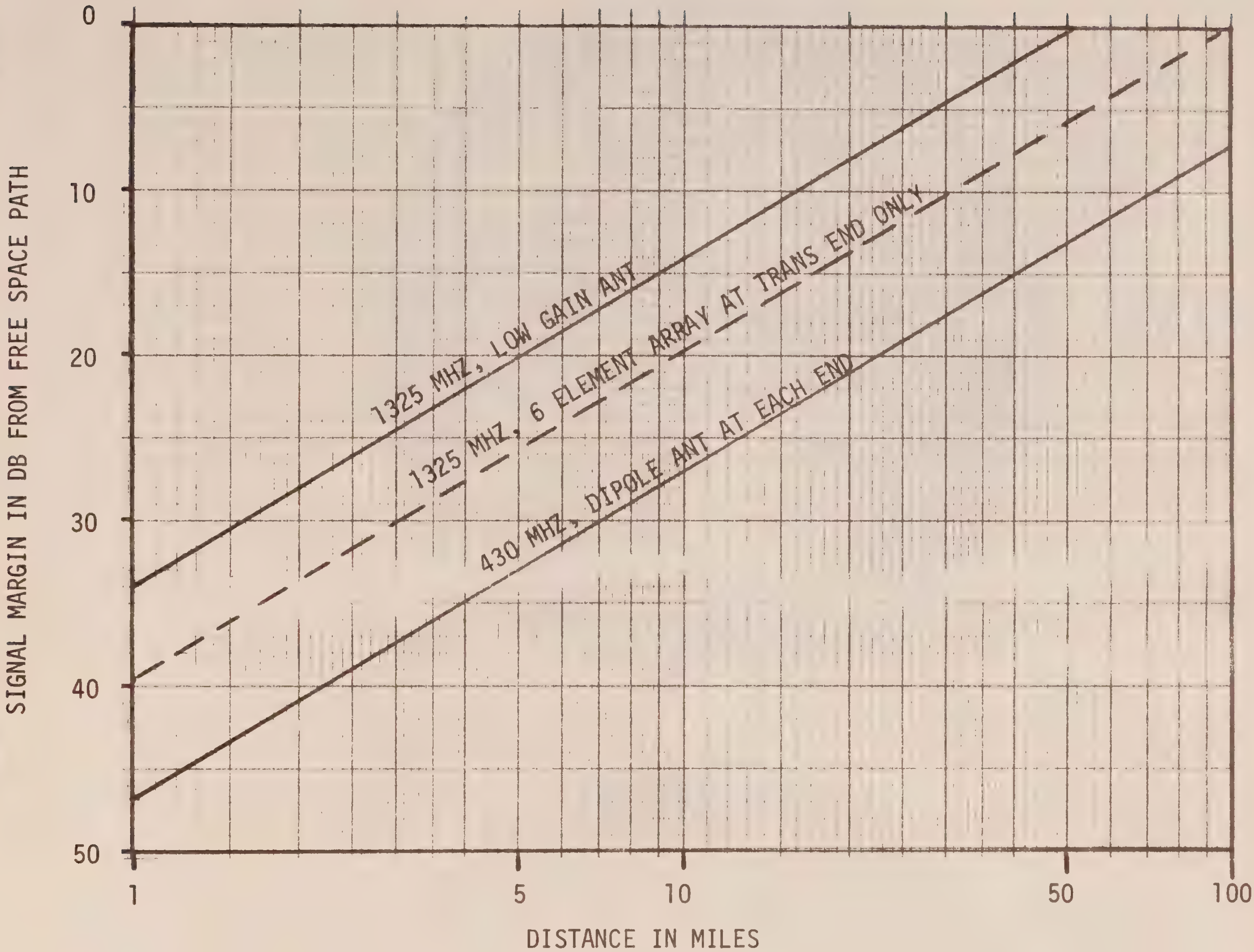


Figure 5-1

SIGNAL MARGIN AS A FUNCTION OF RANGE FOR
430 AND 1325 MHz SYSTEMS

Signal margin is defined as the signal above 0 db S/N in the IF bandwidth which corresponds to about 20 db S/N at correlator output. This is considered the minimum useable signal; hence, the margin represents approximately the maximum obstruction loss that may be tolerated for a satisfactory multipath measurement.

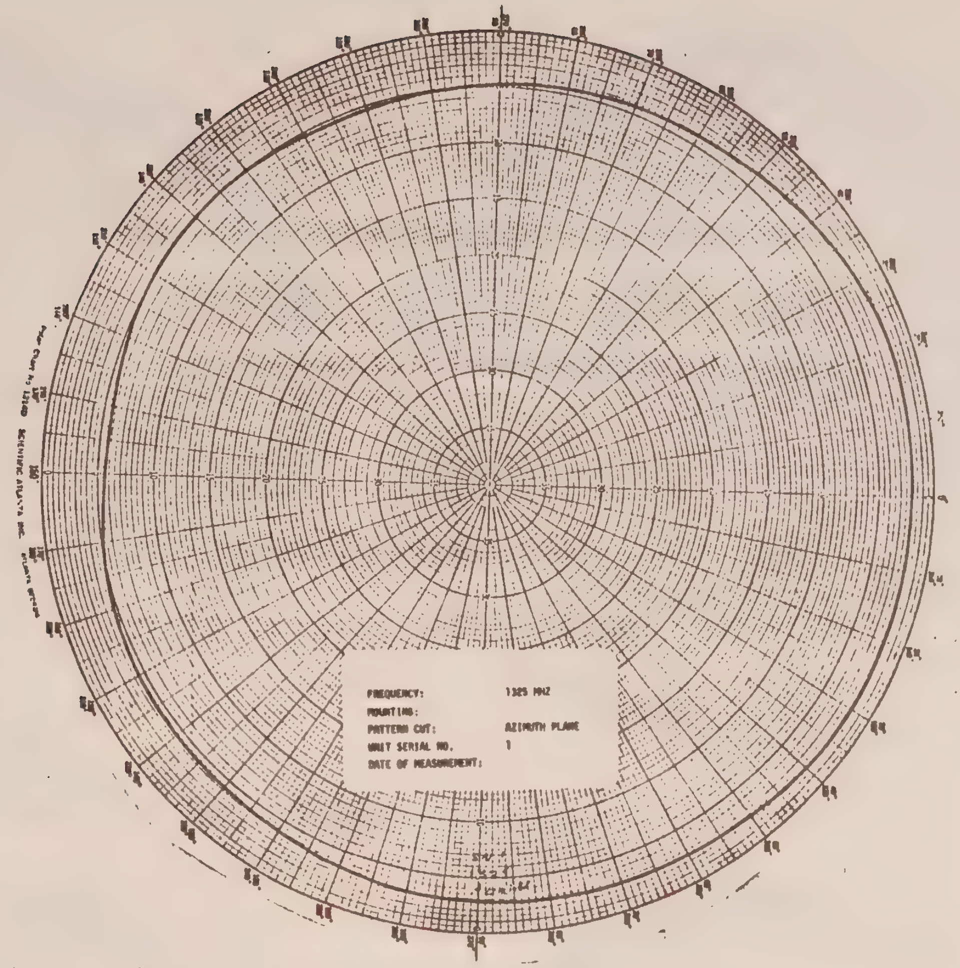


FIGURE 6-1

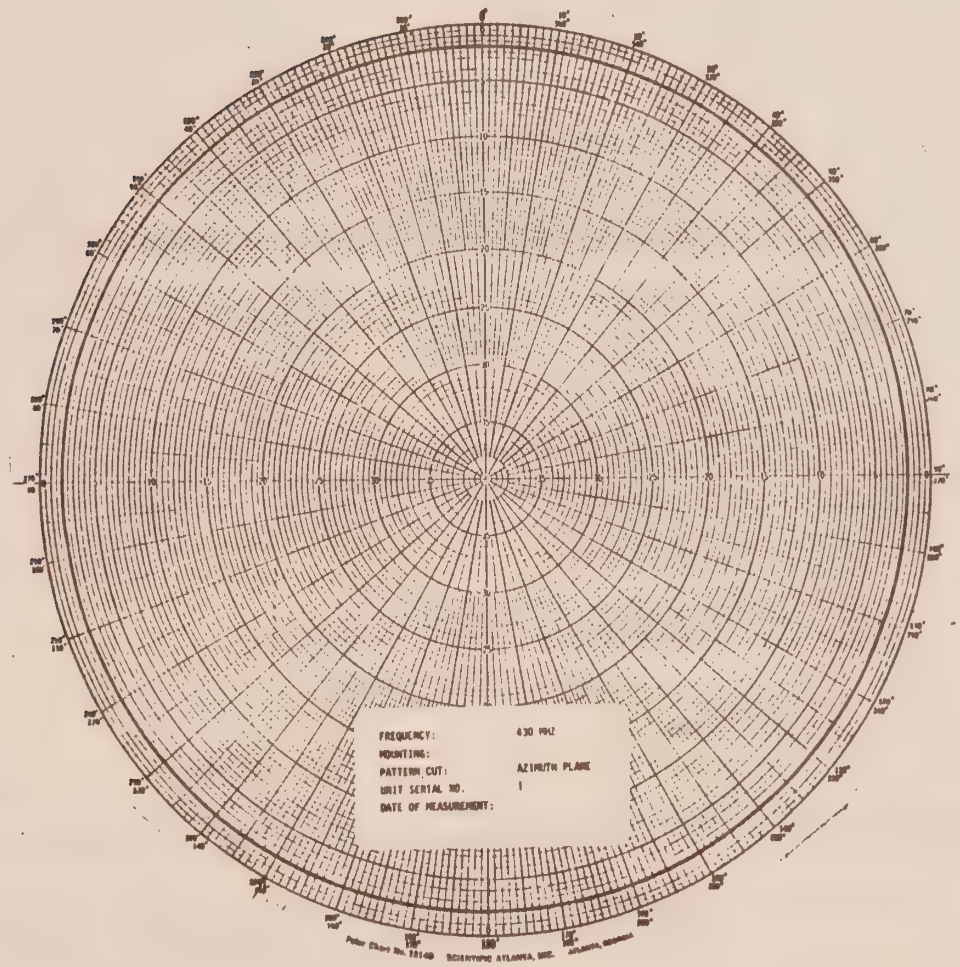


FIGURE 6-2

AZIMUTH PLANE PATTERNS OF 2-FREQUENCY
LOW GAIN ARRAY. BAND CENTERS ARE 430 AND 1325 MHZ.

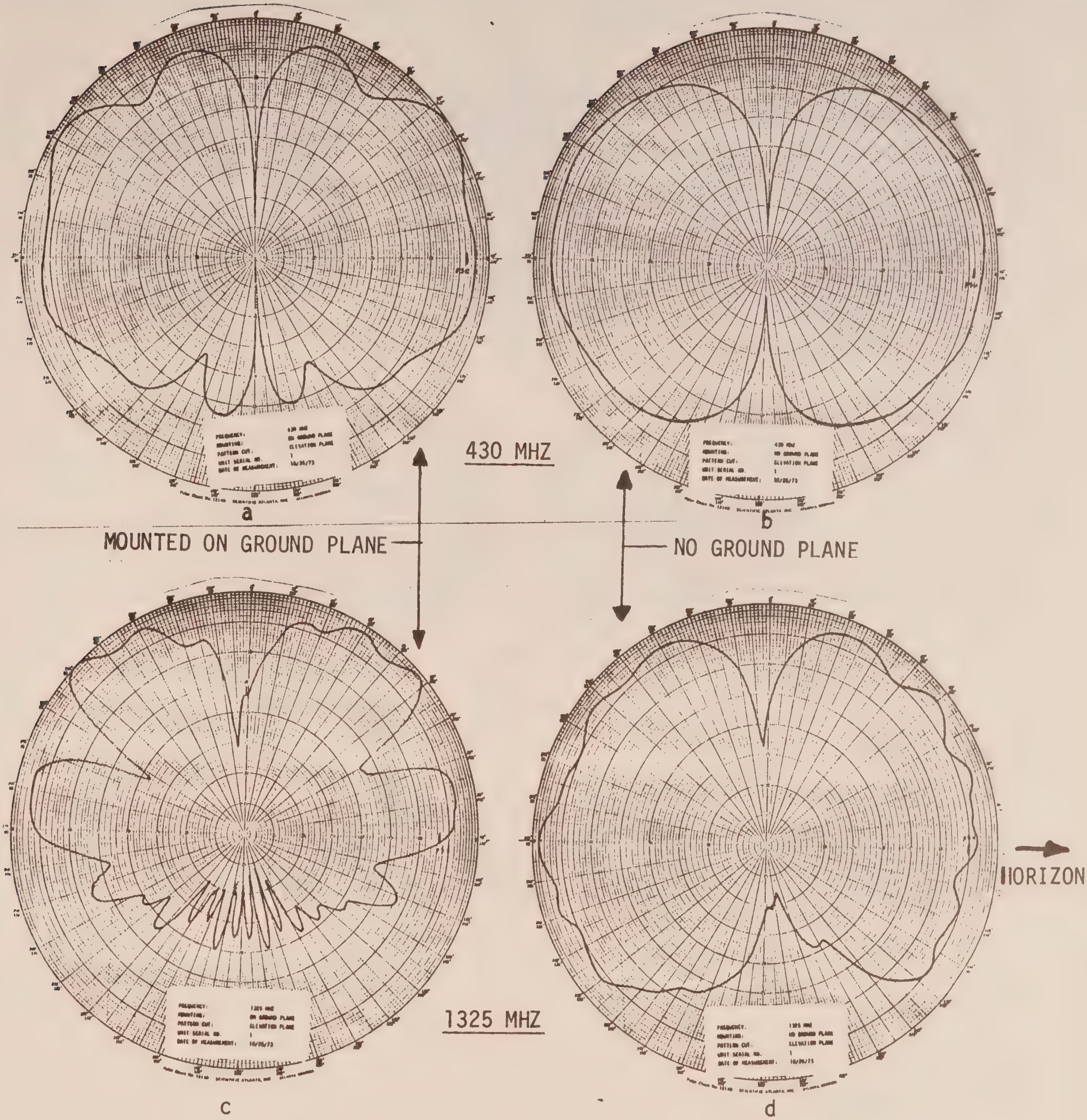


Figure 6-3

ELEVATION PLANE

ANTENNA PATTERNS OF FINAL MODEL OF TWO FREQUENCY LOW GAIN ANTENNA.

NOTE EFFECT OF GROUND PLANE ON ELEVATION PATTERNS. ISOTROPIC GAIN REFERENCE IS MARKED TO RIGHT ON EACH PATTERN.

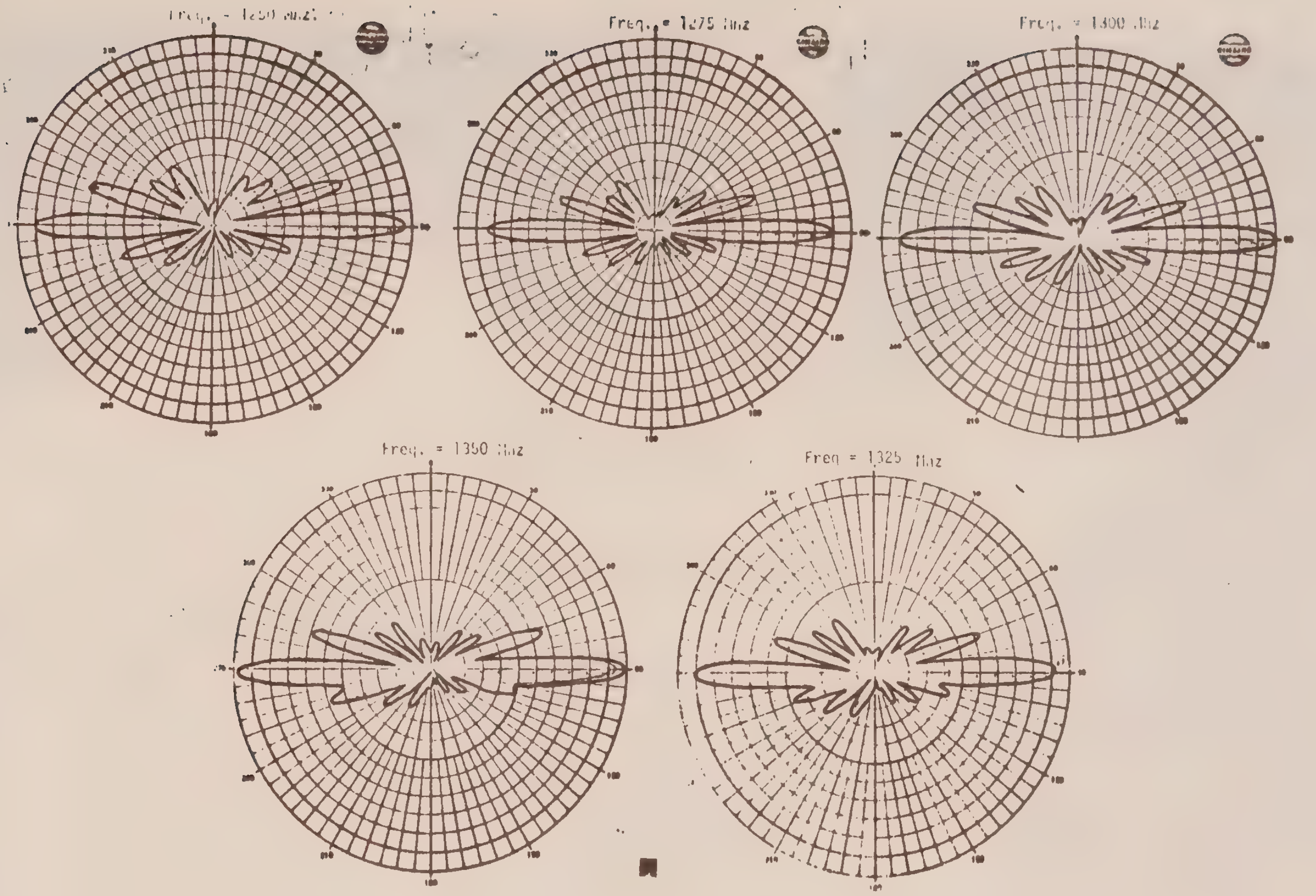
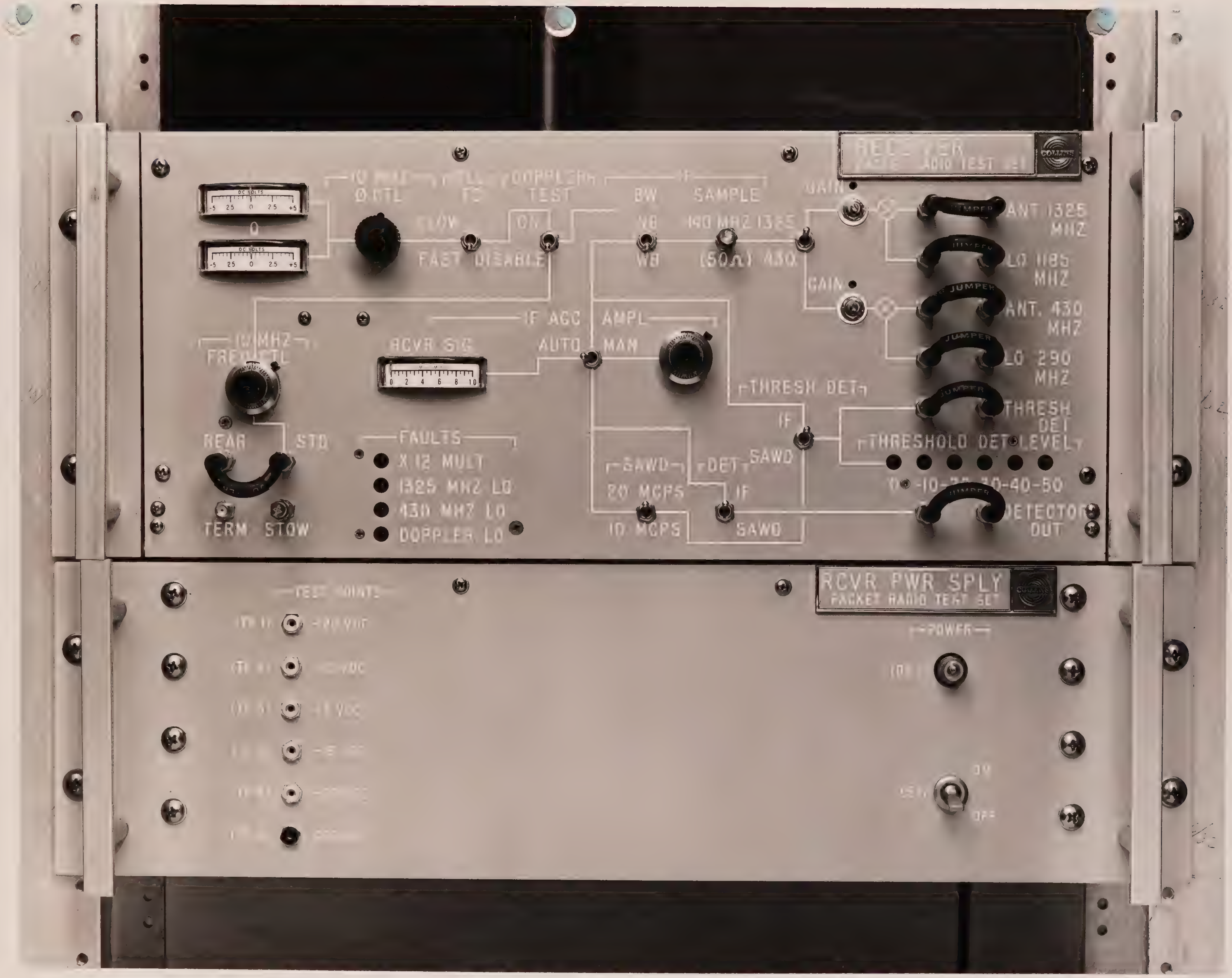
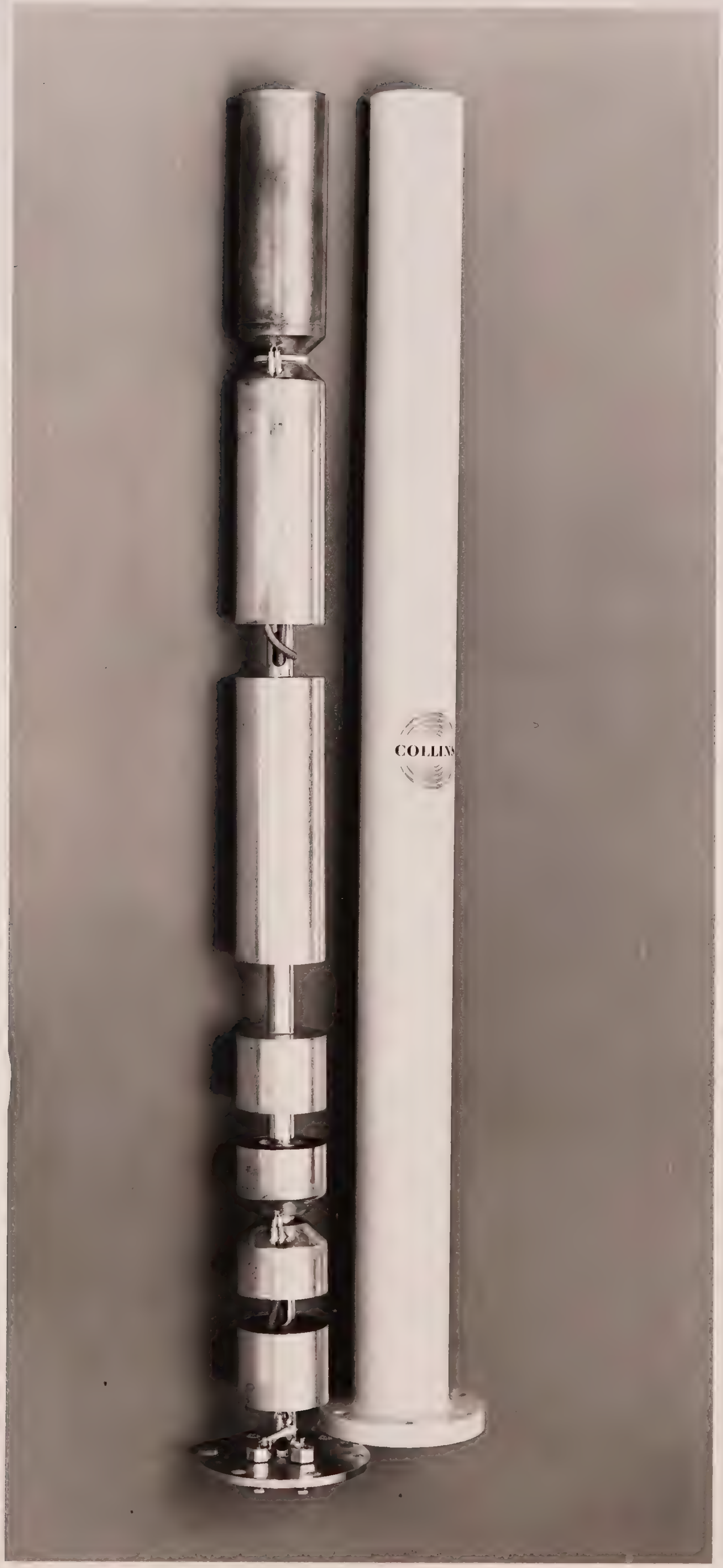


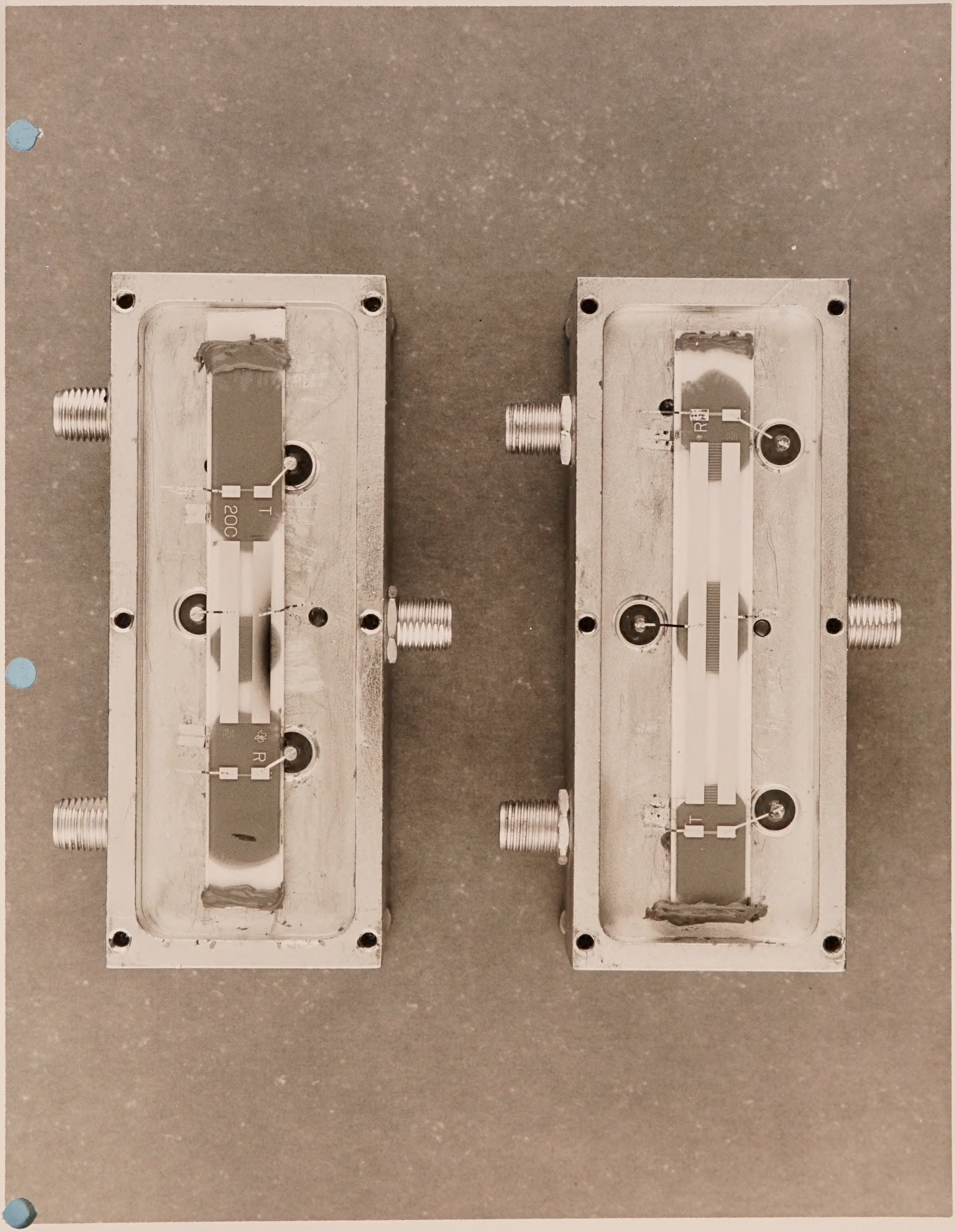
Figure 6-4

ELEVATION PLANE PATTERNS OF
ENGINEERING MODEL 6-ELEMENT COLINEAR ARRAY.
OVER FREQUENCY BAND 1250 TO 1350 MHZ AZIMUTH PLANE PATTERNS IN
PLANE OF MAIN LOBE IS ESSENTIALLY CIRCULAR. MAX GAIN ≈ 7.5 DB


TRANSMITTER


RCVR PWR SPLY
PACKET RADIO TEST SET
ANT 1325 MHZ
LO 1185 MHZ
ANT. 430 MHZ
LO 290 MHZ
THRESH DET
THRESHOLD DET LEVEL
DETECTOR OUT
GAIN
GAIN
DOPPLER TEST
ON
DISABLE
SLOW
FAST
BW
NB
WB
SAMPLE
140 MHZ 1325
(50Ω) 430
IF AGC
AUTO
MAN
AMPL
RCVR SIG
THRESH DET
IF
SAWD
DET
SAWD
20 MCPS
10 MCPS
FAULTS
X 12 MULT
1325 MHZ LO
430 MHZ LO
DOPPLER LO
REAR
STD
TERM
STOW
JUMPER
TEST POINTS
POWER
ON
OFF


COLLINS


T
20C
R
R
T